Regional Climate Projections over Spain: Atmosphere. Future Climate Projections

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Introduction

Regional climate information is increasingly being demanded by vulnerability, impact and adaptation (VIA) research communities. This information is required to feed impact models for specific sectors (health, energy, food availability, risk management, water resources) and for decision-making processes at different levels. Different global and regional climate change projections for the 21st century have been produced over the last decades using both dynamical regional climate models (RCMs) and statistical downscaling methods (SDMs) in a series of international and national initiatives. As a result, large ensembles of future global (e.g. CMIP3, CMIP5) and regional (e.g. ENSEMBLES, CORDEX) climate projections are available, sampling most of the uncertainties affecting climate change. Nowadays, users are confronted with the technical and ethical (distillation) dilemma of deciding which information out of the large amount of available data is best suited for their application, in order to address the different sources of uncertainty for their specific region/problem (Hewitson, 2013).

Regional Climate Change Scenarios for Spain

The Earth System Grid Federation (ESGF, https://esgf.llnl.gov) infrastructure provides standardized access to the last-generation climate change model output data (from CMIP5 and CORDEX). However, the direct use of ESGF is still complex and slow for an average user and therefore there are still several portals providing scenario data (e.g. for a particular region), as well as sector-specific derived indices (Hewitson et al., 2017).

In Spain, the main sources of regional climate change information have been collected by the Escenarios-PNACC initiative. The first dataset (Escenarios-PNACC, 2012) was based on CMIP3 projections from global circulation models (using B1, A1B and A2 greenhouse gases emission scenarios), and provided information for temperature and precipitation and several derived indices (e.g. percentiles). Besides the European-wide dynamical regional climate change projections provided by the EU-funded ENSEMBLES project (Déqué et al., 2012), and the contribution from AEMET (statistical downscaling methods), this initiative was fed with the outcomes of two strategic actions (ESCENA and ESTCENA, for dynamical and statistical downscaling, respectively) undertaken by the Spanish scientific community on regional climate change projection in the framework of the Spanish R+D 2008–2011 Program. The dynamical simulations complemented those produced in ENSEMBLES, focusing on a domain centered in the Iberian Peninsula (Fernández et al. 2012; Jiménez-Guerrero et al. 2013, Domínguez et al., 2013). The statistical downscaling scenarios were produced with different analog- and regression-based downscaling methods (Gutiérrez et al. 2012). The observational data set was based on a selection of stations provided by AEMET and on the gridded observations provided by Spain02 v2.1 (regular grids, at a 20 km resolution; see Herrera et al. 2012). More information and links to access data are described in Escenarios-PNACC (2012).

There have been a number of studies analysing these results and assessing the limitations of the different datasets forming Escenarios-PNACC 2012, focusing mainly on temperature and precipitation. For instance, Turco et al. (2015) analysed the ENSEMBLES regional projections for daily maximum temperature and precipitation over Spain, and found consistent changes up to 2050 (A1B scenario) among the different members, generally indicating a decrease in precipitation (between -5 and -25 %) and an increase in maximum temperature (between 1 and 2.5°C, depending on the season/area). Gutiérrez et al. (2013) reported a limitation of generic analog based methods to extrapolate future temperatures for the last decades of the century. Therefore, those results should be used with caution for studies sensitive to this fact. Moreover, San-Martín et al. (2017) found a good agreement between dynamical (ENSEMBLES) and statistical (ESTCENA) regional projections for precipitation over Spain, although during summer and autumn the statistical methods exhibited a large uncertainty for different families (regression vs. analog methods).

There have been also some studies analysing additional variables such as snow, wind speed or dry spells. For instance, Pons et al. (2016) reported a decreasing trend in annual snowfall frequency (measured as the annual number of snowfall days) from the ENSEMBLES regional projections, with member values ranging from −3.7 to −0.5 days decade^{-1} (−2.0 day decade^{-1} for the ensemble mean). These future trends are similar to the historical observed ones since 1970 (−2.2 days decade^{-1}), and are mainly determined by the increasing temperatures. Gómez et al. (2016) analysed wind speed using ENSEMBLES data and found that the wind speed for 2031–2050 is reduced up to 5% compared to the 1980–1999 control period for all models. The models also agree on the time evolution of spatially averaged wind speed in each region, showing a negative trend for all of them. López-Franca (2015) analysed dry spells over Spain and found an increase of the probability of occurrence of long dry spells together with a decrease in the shorter ones.

The uncertainty of regional climate projections due to model physics has been also addressed for the specific case of the Iberian Peninsula. For instance, Jerez et al. (2013) showed that the spread of multi-physics ensembles are of the same order of magnitude that multi-model ensembles, and that model projections intensity does not depend on bias at present simulations. However, the spread could depend on the synoptic conditions that are usually different in future climates. In addition, Jerez et al. (2012) assesses the influence of the land-surface processes simulation, particularly the contribution of soil moisture modelling in perturbed climates, and its great importance on transitional climate zones.

These studies provide comprehensive information on the Escenarios-PNACC dataset, although further research is needed to understand the methodological and practical limitations of regional projections, particularly the extrapolation capability of the different methods, i.e. the robustness of the stationarity assumption.

Besides the PNACC activities, there have been also a series of studies of regional climate change projections in Spain, which are also valuable for regional studies. For instance, Osca et al. (2013) describes the application of a weather-type technique for precipitation over Spain. Ribalaygua et al. (2013) describes the results of a two-step analog method for regional projection in Aragón. Gómez-Navarro et al. (2010) presents the results of long dynamical projections for Spain with the MM5 model. Pérez (2014) and Gonçalves (2014) describe dynamical downscaling results using WRF over the Canary Islands and Mediterranean Spain, respectively. Ramos et al. (2013) analysed CMIP3 precipitation projections with a SDM.

An update of Escenarios-PNACC is being prepared, based on the new information produced using CMIP5 global projections (focused on the RCP2.6, RCP4.5 and RCP8.5 scenarios). The new edition (Escenarios-PNACC 2017) is based on the research done by Spanish groups in the framework of the EU VALUE SDM intercomparison project (Maraun et al., 2015), and the RCM projections produced in the context of the EURO-CORDEX (Jacob et al., 2014) and MED-CORDEX (Ruti et al., 2016) initiatives. The update of the observational dataset is Spain02 v5 (at 10km resolution, both regular and rotated grids). Most of this information is already available (with daily temporal resolution) at http://www.aemet.es/es/serviciosclimaticos/cambio_climat and http://www.meteo.unican.es/escenarios-pnacc

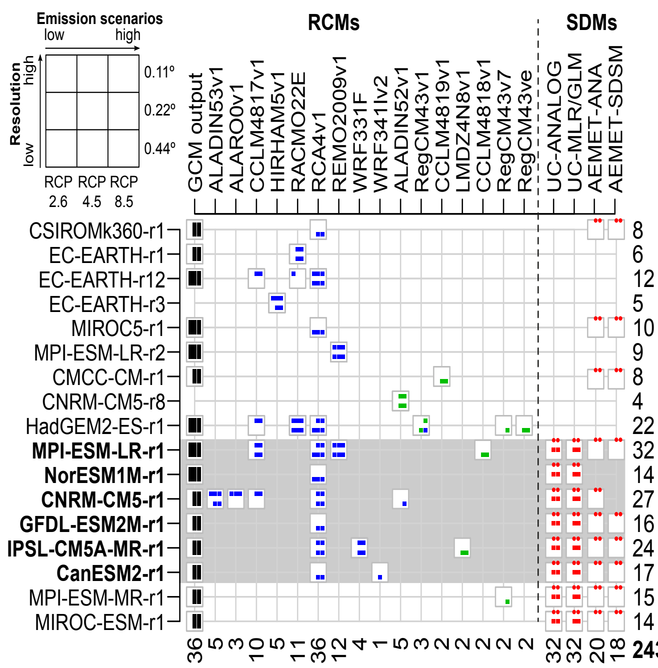

Figure 1: GCM-RCM matrix for the dynamical (blue from EURO-CORDEX, green from MED-CORDEX) and statistical (red) ensemble of regional projections from CMIP5 data available as of April 30th, 2017. Numbers show the number of ensemble members (marginal frequencies) for a given GCM (rows) or RCM/SDM (columns). The available projections comprise simulations at three resolutions (0.11º, 0.22º and 0.44º) and for three RCP scenarios (RCP 2.6, 4.5 and 8.5), as displayed in the matrix shown in the upper-left corner. Note that statistical downscaling methods provide local (station-based) information (denoted by the points over the square boxes) and, in some cases, also areal grid-box information (downscaled from Spain02 v5). Additionally, AEMET statistical downscaling point estimates are also available for 14 other CMIP5 GCMs for ANA and 10 for SDSM, not shown in this table.

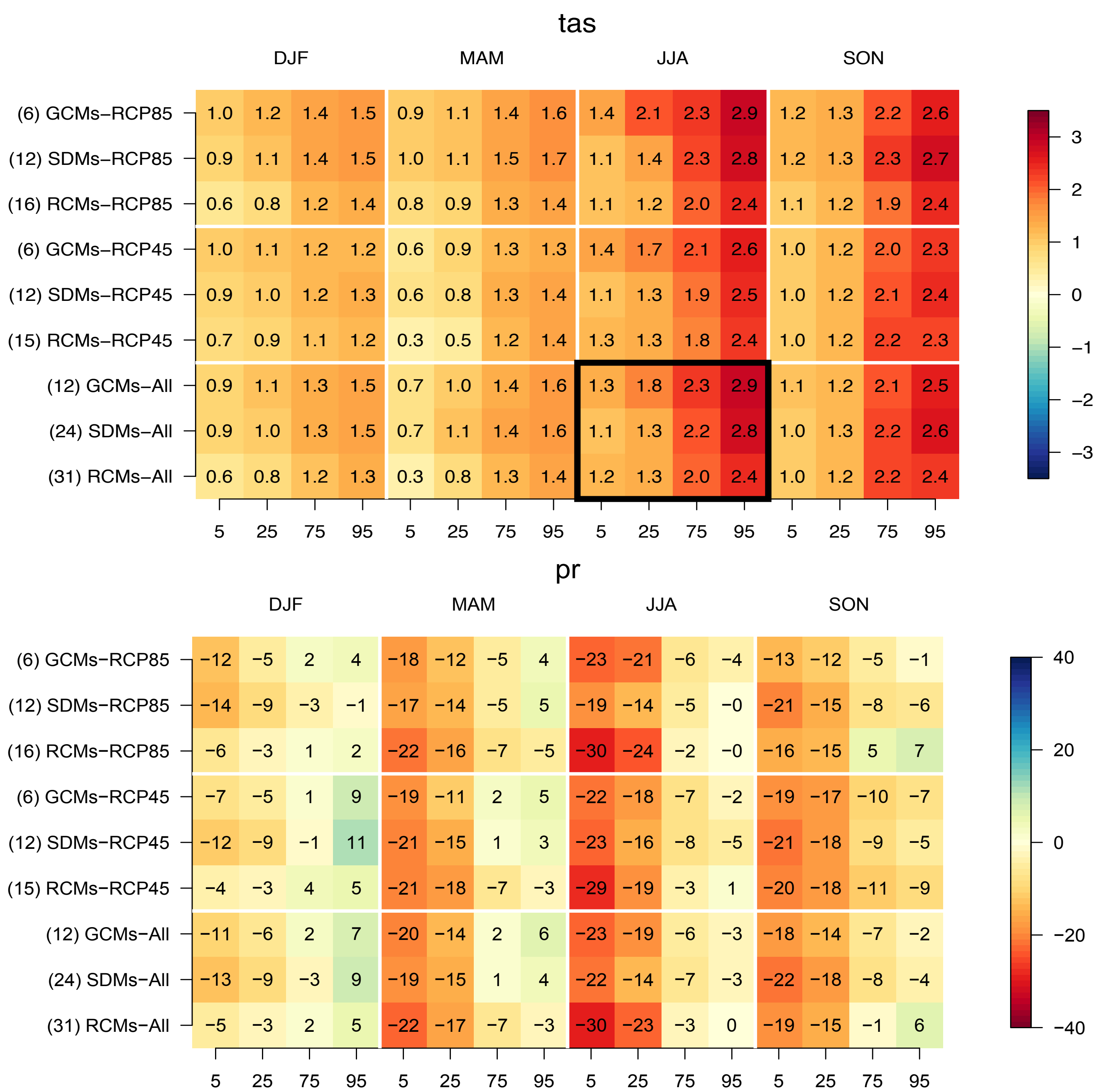

Figure 2: Projected changes for seasonal temperature (ºC, top) and precipitation (%, bottom) by 2021- 2050, with respect to the average of the 1971-2000 period, on average for continental Spain and the Balearic Islands for two different forcing scenarios (RCP8.5, RCP4.5 and both "All") considering the GCM, SDM, or RCM projections (in different rows for each scenario). In order to provide comprehensive information about the ensemble uncertainty in the climate change signal, different percentiles (5, 25, 75 and 95) are given for each case. The range 25-75 is the typical value used to characterize the ensemble spread, whereas 5th and 95th values characterize the extreme signals within the ensemble

Figure 1 shows the information already available from Escenarios-PNACC 2017, with a GCM-RCM/SDM matrix for the multi-project ensemble considered in this study and publicly available as of April 30th, 2017. The numbers show the marginal contribution to the ensemble for each particular GCM (in rows) and RCM/SDM (in columns). These include different forcing scenarios and RCM resolutions (see figure caption). For each GCM-RCM/SDM couple, boxes indicate the available spatial resolutions (0.11º, 0.22º and 0.44º) and RCP scenarios (RCP 2.6, 4.5 and 8.5). Note that, besides the two spatial resolutions, SDMs also provide local (station based) projections for a number of stations (over 2300 selected by AEMET). This makes a total of 255 regional projections available, forming a large multi-model multi-downscaling ensemble sampling the regional uncertainty for climate change projections over Spain. This dataset will be the basis for future regional climate change studies in Spain.

Figure 2 shows projected temperature and precipitation changes by 2021-2050 averaged over continental Spain and the Balearic Islands. It includes only the set of GCMs downscaled by dynamical and statistical models for the same RCP and spatial resolution, thus forming a balanced ensemble representative of regional uncertainties (grey shadow in Figure 1). Projected changes are presented as central 50% and 90% ranges (obtained from the 25th-75th and 5th-95th percentiles of the ensemble), estimated by different sub-ensembles, and for different seasons. For precipitation, there is a general trend to decreasing average precipitation in all seasons, although the expected range of change is only completely on the drier side during summer, reaching an average decrease of -30% for RCM estimates. Regarding temperature, the largest increases are expected in summer and autumn, reaching close to 3°C with respect to the 1971-2000 climatology in the upper end, and no less than 1°C in the most conservative estimates. GCMs tend to provide warmer estimates, which are matched in the upper end by SDMs. These, however, show larger spread and colder lower ends. RCMs provide, in general, colder estimates.

A description of the EURO-CORDEX projections at European level is given in Jacob et al. (2014), which also presents a comparison of the results with the previous ENSEMBLES scenarios. Some statistical downscaling studies building on CMIP5 data have been recently published analysing different aspects of climate change projections in Spain. For extremes, Monjo et al. (2016) applied a two-step analogue/regression downscaling statistical downscaling using CMIP5 predictors over Spain, and analysed 50 and 100-year return values for precipitation. They found that the projected changes were in general smaller than the natural variability. Future changes in extremes such as tropical-like cyclones phenomena (known as "medicanes" when located over the Mediterranean sea) in oceanic regions around the Iberian Peninsula have been studied with CMIP5 models (Romero and Emanuel, 2017) or ENSEMBLES RCMs (Romera et al., 2017)

Impact Studies and Bias Correction

There have been also a number of studies analysing the impact of climate change projections in different sectors using climate-related indices building on regional climate information. For instance, Bedia et al. (2013, 2014) analysed fire danger projections over Spain using the Fire Weather Index (FWI), and statistical/dynamical projections with CMIP3/ENSEMBLES data, respectively. Resco et al. (2015) and Lorenzo et al. (2016) analysed winegrowing in Spain using different bioclimatic indices and ENSEMBLES data. Jerez et al. (2015) analysed photovoltaic power generation in Europe using EURO-CORDEX data. Esteve-Selma (2012) studied the future distribution of Tetraclinis articulata (an endemic Mediterranean tree). Bafaluy (2014) investigated a number of climate indices relevant for tourism using ENSEMBLES data. Casanueva et al. (2014) introduced the direct application of statistical downscaling to multi-variate climate indices for fire danger and tourism.

One of the main problems found in impact studies when analysing climate-derived indices using RCM data is the effects introduced by model biases. Casanueva et al. (2016) provides a detailed analysis of EURO-CORDEX biases over Spain. This has motivated a huge research activity over the last two decades in order to find suitable bias adjustment methods, able to correct model biases against a reference high-resolution climatology. An intercomparison of different bias adjustment methods over Europe, using ENSEMBLES data, is provided in Dosio et al. (2012). Several impact studies have explored the use of these techniques. For instance, Ruiz-Ramos (2016) analysed the application of several bias correction methods for improving crop impact projections in the Iberian Peninsula for 21st century. Gabaldon-Leal (2015) used bias corrected ENSEMBLES data to analyse summer crops in the southern Iberian Peninsula, focusing on the impacts of rising temperatures, and of higher frequency of extreme events on irrigated maize, and to evaluate some adaptation strategies.

Further research on bias correction methods include the work by Romero et al. (2011), presenting a new parametric trend-preserving bias correction method, and by Turco et al. (2017), introducing a new methodology for correcting and downscaling RCM data based on an analog technique.

Distillation of global and regional scenario results

VIA research communities are usually advised to consider an ensemble of model projections, or at least a selection of members spanning the ensemble uncertainty, in order to propagate the uncertainty arising from different greenhouse gases emission scenarios and (global and regional) climate models. However, the distillation of information out of the large amount of available data is a technical and ethical challenge (Hewitson et al., 2013). It is still not clear how to best proceed in order to select a subset of representative data (out from the large ensemble available) for a particular study (Cannon, 2015). Moreover, different datasets could provide inconsistent or even conflicting information making this process even harder. This is one of the key challenges considered in ongoing initiatives (e.g. the "distillation of climate information" work package within EURO-CORDEX), and further advances are expected in the coming years.

In order to illustrate this problem, we will see that the simple summary of ensemble members in percentile ranges shown in Figure 2 is misleading. Ensemble

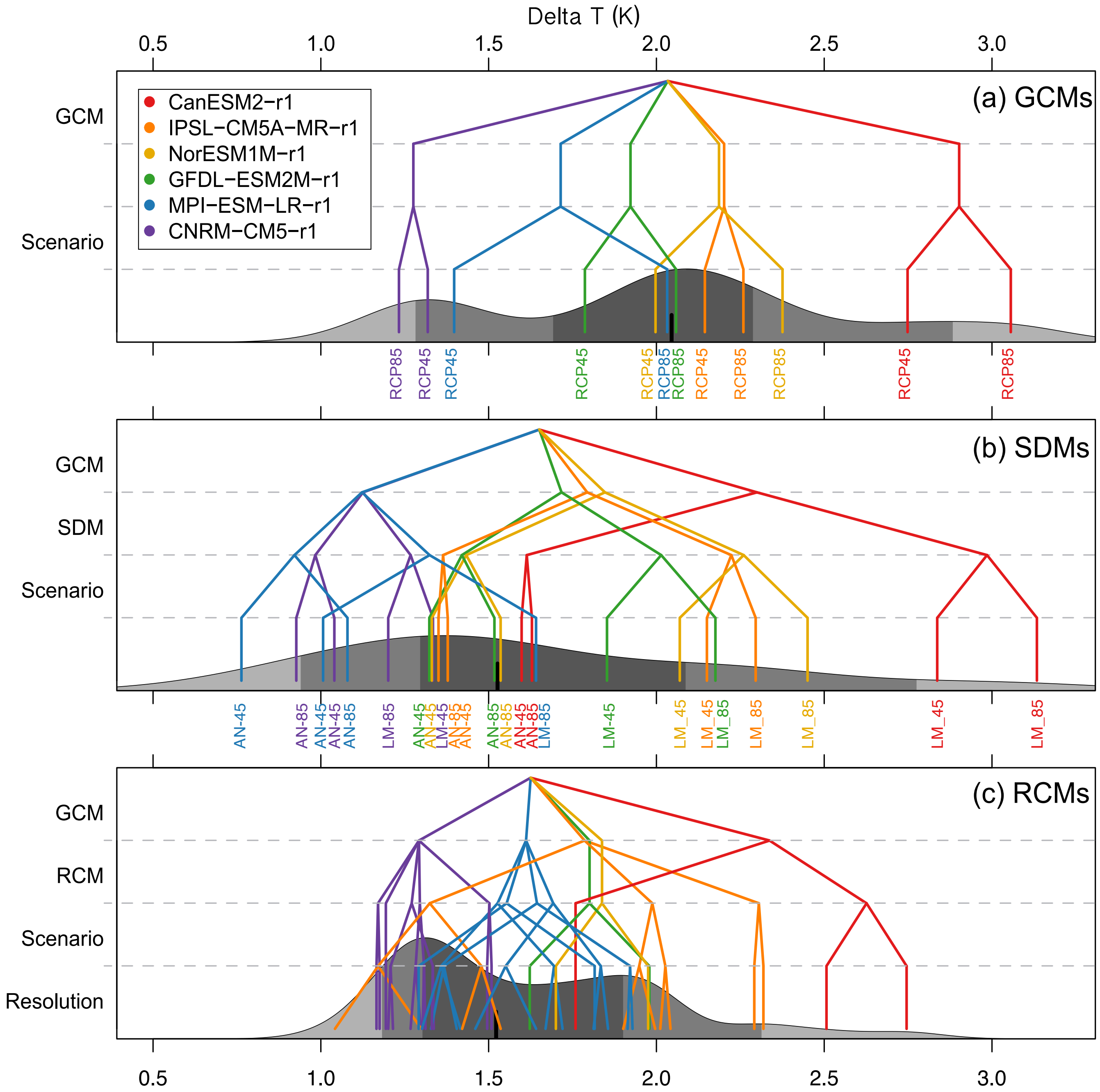

Figure 3: Summer (JJA) temperature deltas (2021-2050 vs 1971-2000) averaged over continental Spain and the Balearic Islands. The 255 ensemble members considered in this work have been split into sub-ensembles considering only (a) GCMs, (b) SDMs and (c) RCMs. In each case, the lines at the bottom depict all sub-ensemble member deltas and are averaged at the joints as the plot progresses upward to the upper joint representing the sub-ensemble mean. Probability density functions are estimated for each sub-ensemble and 50% and 90% central range estimates are depicted as shades. See Fernández et al. (2017) for more information.

members are not independent and specific features of downscaling methods, and (lack of) ensemble design, are behind the different climate change ranges shown. As an example, we focus on summer temperature change (squared in Figure 2) and show individual results (Figure 3) for the three sources of future projections (GCMs, SDMs and RCMs). Individual delta change estimates at the bottom are coloured by the driving GCM, which is the largest source of uncertainty (spread). There are GCMs, such as CanESM2, ranking in the upper end of the temperature change (Figure 3a), while others (e.g. CNRM-CM5, MPI-ESM) tend to project smaller changes. This trend is essentially preserved by downscaling methods (Figure 3b,c) with some particularities. In SDMs, the statistical method used (linear model -LM- or analogues -AN-) is a large source of spread, with analogue methods ranking clearly at the lower end due to their inability to extrapolate temperatures beyond the observed range. On the other hand, the RCMs, which are more physically based, are computationally very expensive, and the available GCM population has been very unevenly sampled. In this example, RCMs have favoured two of the GCMs projecting the smallest delta changes (CNRM and MPI models). This fact, along with a genuine tendency by the RCMs to project smaller delta changes (potential added value) results in a narrower range and smaller mean temperature change than projected by GCMs.

Acknowledgements
We thank the modelling groups contributing to the CORDEX and CMIP initiatives, which provided data for this study through the ESGF infrastructure. The authors also want to thank, in particular, Petra Ramos (AEMET), Emma Gaitán (FIC), Jesús Asín (Univ. Zaragoza), Romu Romero (Univ. Islas Baleares) and Carmen Llasat (Univ. Barcelona) for providing a review of previous works.

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